Strain-induced coupled quantum rings in Si-based nanostructures

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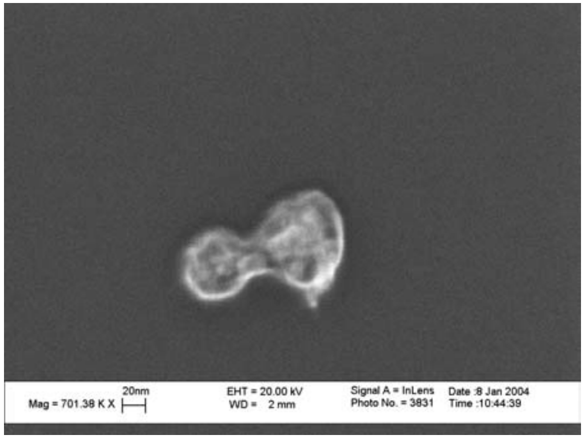
We have been studying the interplay between mechanical strain relaxation and electronic properties of ultra-small quantum dots and discovered the confinement of carriers to the perimeter of a sufficiently small nanostructure [1].

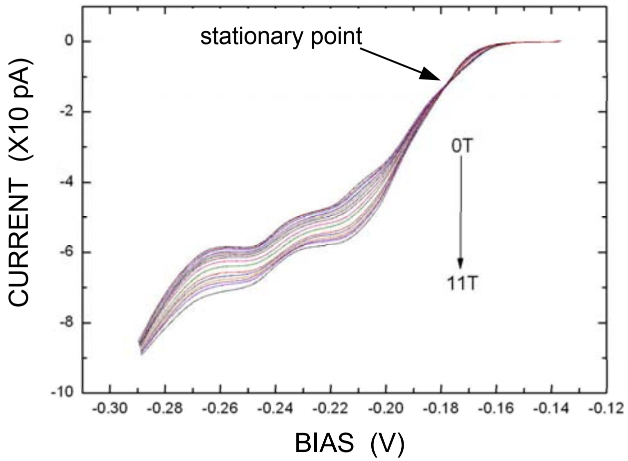
This permits, in principle, the fabrication of unique structures by etching a sub-100 nm figure-eight pillar (carriers will flow along the perimeter, leading to a coupled quantum ring). Coupled quantum rings have unexplored physical properties.

During the past year, we have perfected the fabrication of coupled-ring structures and began studying their transport properties by magnetotunneling spectroscopy. The magnetotunneling characteristics observed in our recent structures exhibit unexplained "stationary points" (points through which all $I(V)$ curves pass, regardless of magnetic field) – this interesting effect still awaits explanation

[1] J. Liu, A. Zaslavsky, and L. Freund, Phys. Rev. Lett. 89, 096804 (2002).



Top view of sub-100 nm coupled quantum ring contact.



Preliminary magnetotunneling characteristics

Motion of electrons in electrical circuits is usually detected by measuring the current, which is a flow of millions of electrons. The situation is much different in the case of nanoscale objects, called quantum dots whose behavior is dominated by only a few loosely bound electrons. Working in the field of quantum information science, we have shown that it is possible to control the rate at which the electrons escape the quantum dots. For example, we have developed devices such as a Single Electron Transistor (SET) that can be switched on or off with the addition of a single electron. With our collaborators from Bell Laboratories, we have used a special type of SET and detected the motion of individual electrons in and out of a semiconductor quantum dot. The experiment was done at temperatures only a few hundredth of a degree above absolute zero. We measured the output signal from the SET in a coded way and transformed it so we can see the changes in the SET signal in real time. Our group observed sudden changes in the SET output and showed that these changes correspond to individual electrons moving in and out of the tiny semiconductor dot in roughly ten millionth of a second. This is the first time that individual electron flow had been determined via an SET, and is of considerable interest from the standpoint of new quantum device development. This work was published in the May 22, 2003 issue of Nature.

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Education:

Three graduate students (Guohua Wang and Dapeng Wang from Physics and Brian R. Perkins from Engineering) are participating in this work in the PI's lab. An undergraduate (David Greci) completed his senior EE thesis on coupled-ring fabrication in spring of 2004 (he will start his Ph.D. studies at Columbia Univ. this fall). In addition, a collaboration with the solid mechanics group (Prof. V. Shenoy and graduate student Dhananjay Tambe) who are experts at calculating strain in nanostructures is ongoing.

As part of the educational component, the PI is designing a hands-on device fabrication lab for our "Solid State Devices" junior-level EE course -- the first run will be during the fall semester of 2004.

Societal impact:

The proposed research will shed light on a fundamental physical system – the quantum ring – that has no immediate technological relevance today. However, in the future coupled quantum rings have been suggested as a possible solid-state implemention of basic quantum computing elements (qubits).

The main impact of our work is to advance basic science of coupled quantum rings. It will also provide experimental feedback on the interplay between electronic and mechanical properties of nanostructures, which is of key importance to rapidly evolving semiconductor devices (e.g. strained quantum dot lasers).